EVALUATING MODIS VEGETATION INDICES USING GROUND BASED MEASUREMENTS IN MOUNTAIN SEMI-NATURAL MEADOWS OF NORTHEAST PORTUGAL

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ABSTRACT

The sustainable conservation of mountain semi-natural meadows depends on the knowledge of their vegetation dynamics and management practices. Time series of vegetation indices (VI) derived from high temporal resolution satellite images can be a useful tool to the sustainable management of semi-natural meadows ecosystem and grazing activities. In this study satellite VI from the Moderate Resolution Imaging Spectroradiometer (MODIS) are evaluated against in situ measurements of VIs and plant height in the semi-natural mountain meadows of Northeast Portugal. In two testes sites, we evaluated the performance of Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) from MODIS and field spectroradiometer sensor in characterizing semi-natural meadows phenology and plant height. The Savitzky-Golay filter was used for smoothing each VI time series, as well as to extract a number of NDVI and EVI metrics by computing derivatives. There was weak to reasonable agreement between VIs-metrics from MODIS and ground based derived phenology. The NDVI had a great sensitivity to crop growth changes during start of growth season, whereas the EVI exhibited more sensitivity at the pick of the maximum green biomass. The relationship between vegetation height and both VI from MODIS or field spectroradiometer, fit a non-linear model with similar pattern function for each test site. Regression analysis revealed that 67% of the in-season plant height variability could be explained by $MODIS_{EVI}$. These results suggest a great sensibility of $MODIS_{EVI}$ to detect the phenology and plant height of semi-natural meadows, even in situations of high plant height.

Index Terms — Vegetation, Agriculture, Remote Sensing

1. INTRODUCTION

Ancestral semi-natural meadows, locally called “Lameiros”, are an essential element of the mountain landscapes in Northern Portugal. They are mainly used for forage production to feed autochthonous bovine livestock, but they are also important for the water and nutrients cycle regulation, erosion control and as barrier to forest fires propagation. To preserve these meadows, it is essential to gather useful information for the sustainable management of semi-natural meadows ecosystem and grazing activities.

Field surveys of vegetation dynamics monitoring, related with phenology and management practices, although useful are difficult and time-consuming. Hence, alternative approaches, with quick and reliable performance, must be considered and tested, as the case of remote sensing based monitoring.

A great variety of vegetation indices (VI), derived from remote sensing measurements, are commonly used to characterize the growth pattern and production estimates of grass in different biophysics conditions [1-3]. Even so, the accurate estimation of vegetation dynamics and biomass production, validated in natural conditions [2, 4, 5], is still a challenge for remote sensing studies. Among the issues to solve are: i) the reduction of soil background in low canopy cover [6], ii) the atmosphere-induced variations on canopy spectra [7] and iii) the insensitivity of VIs extracted from the red and near-infrared reflectances when biomass or leaf-area-index (LAI) reaches a threshold due to these reflectances asymptotically approach a saturation level [2]. This saturation problem of VIs can result in poor biomass or LAI estimates, mainly in meadows with high vegetation cover [5].

Time-series from the Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) datasets hold great potential for vegetation monitoring in agricultural areas, given their global coverage, intermediate spatial resolution, high temporal resolution, and cost free status [8].

The $MODIS_{NDVI}$ is chlorophyll sensitive and responds mostly to the visible or red band variations. The $MODIS_{EVI}$ is more near-infrared (NIR) sensitive and responsive to canopy structural variations, including LAI, canopy type, and canopy architecture [1]. $MODIS_{EVI}$ is designed to be sensitive to variations in dense vegetation cover [6, 8] compared to $MODIS_{NDVI}$, which is designed to capture changes in low to intermediate vegetation intensities. The $MODIS_{EVI}$ is also designed to remove some of the influences inherent to the mixing of soil/vegetation reflectance signal [7].

The specific spectral-temporal information contained in these VIs from MODIS data has yet to be thoroughly explored and their applicability for vegetation monitoring is relatively unknown.

To improve the estimation of the dynamics of semi-natural meadows having a very high canopy cover based on remotely sensed data, VIs time series from MODIS TERRA, 250 m, are evaluated against 18 months of *in situ* measurements. In this study we evaluated the performance of $MODIS_{EVI}$ and $MODIS_{NDVI}$ in characterizing semi-natural meadows phenology and plant height.

2. METHODOLOGY

2.1. Test sites

This work was carried out in semi-natural meadows of Montalegre municipality in northern Portugal. These meadows are frequently located in areas of high water availability, loamy soils and over 700-800m high. In this region the Atlantic influence favour high precipitation occurrence (1531 mm/year), mainly occurring from autumn to spring. In association with these meadows, traditional irrigation systems can be found, in which the water is applied all year around, to assure the crop water requirements but also to promote a thermal regulation effect [9].

The CORINE Land Cover maps from 2000 and information from field surveys were used to select suitable test sites, with large contiguous areas with semi-natural meadows. Two test sites were defined in Montalegre (Figure 1): Paredes do Rio (PRR, 28 pixels, 250m) and Salto (SLT, 6 pixels, 250 m). These two test sites were established over semi-natural meadows coverage, in compact groups of contiguous satellite pixels, and both including the areas defined for the ground measurements (Table 1).

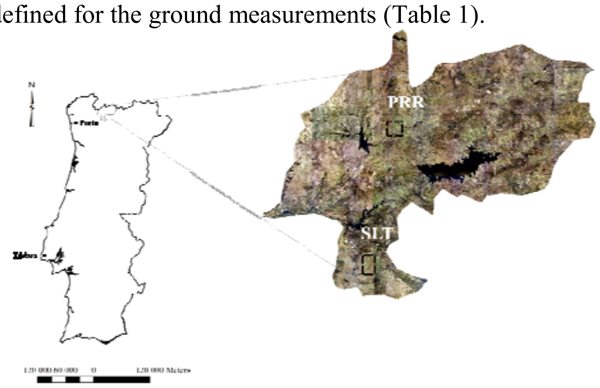

Fig. 1. Location of the study area (Montalegre municipality) and test sites (Paredes do Rio – PRR and Salto – SLT), in the Northeast of Portugal.

In the selected test sites the vegetation is dominated by permanent herbaceous species from *Molino Arrhenatheretea* class with a maximum height of 120 cm.

TABLE 1. COORDINATES AND NUMBER OF PIXELS SAMPLED IN EACH TEST SITES

Test sites	n. pixels (250x250m)	Geographic coordinates (Long/Lat WGS-84)
Salto - SLT	6	UL: 7d57’19W, 41d37’58N BR: 7d56’57W, 41d37’33N
Paredes do Rio - PRR	28	UL: 7d54’34W, 41d48’31N BR: 7d53’40W, 41d47’59N

2.2. MODIS Vegetation Indices

The 16-days MODIS TERRA (250 m) composites from 2001 to 2008 were used to produce NDVI and EVI times series for each test site. The NDVI is a normalized difference measure comparing the near infrared (NIR) and visible red bands :

$$NDVI = \frac{(\rho_{NIR} - \rho_{red})}{(\rho_{NIR} + \rho_{red})} \tag{1}$$

were ρ_{NIR} (846-845 nm) and ρ_{red} (600-680 nm) are the surface reflectance for the respective MODIS bands.
The EVI is defined by the expression [6]:

$$EVI = G.\frac{(\rho_{NIR} - \rho_{red})}{(\rho_{NIR} + C_1 \times \rho_{red} - C_2 \times \rho_{blue} + L)} \tag{2}$$

where ρ values are surface reflectances partially atmospherically-corrected (Rayleigh and ozone absorption) surface reflectances, *L* is a canopy background adjustment term (L=1), and C_1 and C_2 are the coefficients of the aerosol resistance term, which uses the 500 m blue band (458-479nm) of MODIS to correct for aerosol influences in the red band (C_1 = 6 and C_2 = 7.5), and G is a gain factor (G=2.0) [6].

The whole test site was considered as a unit, instead of using a pixel by pixel approach. This was done to prevent misregistration and other sources of errors to contaminate the VIs times series. The pixels of each test site were averaged to create the VIs values for each time period

2.3. Ground Based measurements

Spectral measurements were performed at field level using a handheld spectroradiometer (ASD FieldSpec UV/VNIR) with reflectance data captured between 325nm and 1075nm and conic IFOV of circa 25º. Field reflectance measurements were sampled in 17 points (SLT) and 15 points (PRR). At each measurement, the reflectance was compared with reference calibration panel to account for atmospheric changes. The spectroradiometer field measurements were used to compute NDVI (FSp_{NDVI}) and EVI (FSp_{EVI}) using the corresponded information to the MODIS bands width.

Eighteen campaigns of reflectance measurements were carried out from July 2007 to December 2008, with monthly periodicity sampling all phenological stages of “lameiros”. All measurements were performed in sunny and cloudless days between 11-14 hours.

For all the campaigns in each measurement point of FSp, the vegetation height (Hv) was also measured and the phenological stage recorded.

2.4. Smoothed process and VI metrics

The Savitzky-Golay filter [10] was used for smoothing and suppressing disturbances of each VI time series, as well as to extract a number of NDVI and EVI metrics by computing derivatives. Then the first ($\delta_1(t)$) and second ($\delta_2(t)$) derivatives of the smoothed VI curve were calculated, which represent the change and the rate of change in curvature of the model respectively. The start of growing season or "Green-Up" (GU) was considered when a maximum change rate (δ_2 maximum) and a positive change ($\delta_1>0$) occurs. The maximum vegetation height or "Maximum Greenness" (MG) was considered when a negative change rate ($\delta_2<0$) and a turning point from a positive change to a negative $[(\delta_1(t) \times (\delta_1(t+1))]<0$ occurs.

Paired t-test was performed to compare VI-metrics from MODIS within and inter test site, considering each year (2001 to 2008) a repetition.

The relationship between each calculated VIs and plant height were fitted to the logistic model:

$$VI = \frac{C}{(1 + a \times e^{bHv})} \quad (3)$$

- Hv: meadows vegetation height (cm);
- VI- Vegetation index [ ];
- "C" – constant defining the upper bound of the model;
- "a" and "b" – constants defining the model's shape

3. RESULTS

The Vegetation height and VI-metric derived from MODIS and FSp for each test site in 2008 are presented in table 2. For the two test sites the MG-metrics dates from MODIS and FSp showed differences always below 4 days. However, the dates of the GU-metrics from in situ measurements (FSp or Hv) are generally 20-30 days early than the similar GU-metrics dates derived from MODIS (table 2).

TABLE 2 –VEGETATION HEIGHT (Hv) AND VIS METRIC DERIVED FROM MODIS AND FIELD SPECTRORADIOMETER (FSp) SENSORS FOR EACH TEST SITES IN 2008.

Test site/ sensor	VI	Green Up DOY	Green Up VIv	Max. Greenness DOY	Max. Greenness VIv
SLT test site					
MODIS	NDVI	120	.564	170	.599
FSp	NDVI	73	.542	170	.762
MODIS	EVI	105	.272	170	.346
FSp	EVI	94	.269	170	.346
Vegetation height	*cm*	*96*	*5.5*	*170*	*64.8*
PRR test site					
MODIS	NDVI	105	.523	184	.640
FSp	NDVI	53	.582	180	.770
MODIS	EVI	105	.275	184	.412
FSp	EVI	73	.273	180	.410
Vegetation height	*cm*	*73*	*12.7*	*191*	*117.3*

Data included 18 observations from each test site. FSp: Field spectroradiometer. DOY: day of the year. VIv: value of the vegetation indices.

The values of the MG-metrics derived from EVI (MODIS or FSp) as well as plant height are higher in PRR (117.3 cm) than in SLT (64.8cm). The mean (2001 to 2008) MG-metrics values derived from MODIS are also significantly higher in PRR (Table 3).

Within test site, the values of all EVI-metrics (GU and MG) from both sensors are quite similar (<5%) and contrast with the large differences between sensors in the NDVI-metrics. These NDVI-metrics differences between sensors are particularly higher (about 20%) when the vegetation reach the maximum height and can be related with the saturation problems of the NDVI. The differences between EVI-metrics from both sensors remain constant regardless of the vegetation growth, whereas the NDVI-metrics increase.

These results indicate that the atmosphere has a large influence on the VIs derived from different sensors. The MODIS morning over pass is also more likely to encounter cloud cover than the in situ measurements captured between 11 and 14 hours.

General statistics from MODIS 2001 to 2008, including significance levels for different comparisons between VIs-metrics within and inter sites, are show in table 3.

TABLE 3. STATISTICS OF VI-METRIC DERIVED FROM MODIS (2001 to 2008) FOR EACH TEST SITES.

Statistics/test sites	Start Green Up DOY	Start Green Up VIv	Max. Greeness DOY	Max. Greeness VIv
SLT test site				
Average EVI (1)	100.0	.27	170.0	.35
Average NDVI (2)	110.0	.54	172.0	.60
Coef. of variation (%) EVI	11.3	10.1	4.9	4.9
Coef. of variation (%) NDVI	22.6	6.9	6.6	2.5
PRR test site				
Average EVI (3)	94.0	.27	182.0	.41
Average NDVI (4)	93.7	.52	176.0	.64
Coef. of variation (%) EVI	10.9	11.7	4.5	6.4
Coef. of variation (%) NDVI	15.4	7.0	5.2	2.6
*Mean comparisons by t_test**				
SLT_ EVI x SLT_NDVI (1 x 2)	.175	.000	.175	.000
PRR_ EVI x PRR_NDVI (3 x 4)	.500	.000	.039	.000
SLT_ EVI x PRR_EVI (1 x 3)	.099	.283	.001	.000
SLT_ NDVI x PRR_NDVI (2 x 4)	.024	.086	.178	.000

*P-value associated to the paired t-test. DOY: day of the year. VIv: vegetation indice value.

Within test sites none of the GU-metrics dates derived from NDVI or EVI differed significantly (table 3). No significant differences was found between test sites for the date of GU-metrics derived by EVI ($p<0.099$). However, in SLT the date of GU-metric derived from NDVI (DOY 110) was significantly later (6 days; $p<0.024$) than the corresponding NDVI-metrics for PRR (table 3).

The average date of MG-metrics in SLT was very close to 170 Julian day and no significantly differences ($p<0.175$) between VI was found. In PRR the timing of MG-metric derived from EVI (DOY 182) was significantly later (6 days) than the corresponding NDVI-metrics (DOY 176). Although the differences between test sites were statistically significant for the MG-metrics derived from EVI (12 days; $p<0.001$), no significant differences ($p<0.178$) were found for the same event when estimated by the NDVI. The later occurrence of MG-metrics derived from EVI in PRR can be related with the high vegetation height in these test site that cause saturation of the NDVI.

The relationship between vegetation height and both VI from MODIS or FSp, fit a logistic model (equation 3) with similar pattern function for each test site (Figure 2). Results of statistical tests show that, according to sensors, about 60% (FSp) to 67% (MODIS) of the in-season plant height variability could be explained by the EVI and 44% (FSp) to 55% (MODIS) by the NDVI (Table 4). While both VIs were sensitive to changes in plant height at the beginning of growing season, the NDVI became insensitive to additional growth when grass reached heights of 40 cm (30% of maximum height). The EVI performed reasonably well up to grass plant heights of 60 cm.

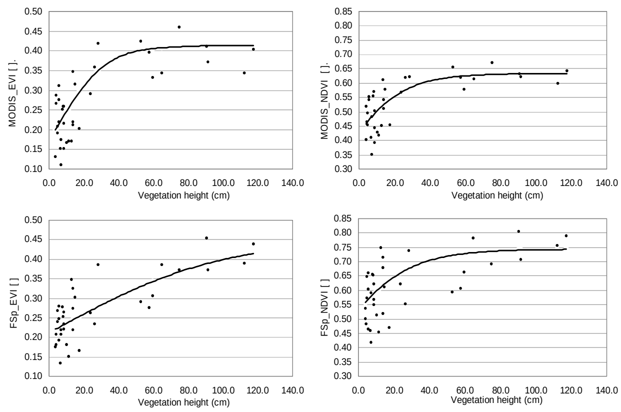

Fig. 2. Relationship between vegetation height and VIs from MODIS or Field Spectroradiometer (FSp) including data from both test sites for the period of July 2007 to December 2008 (n=35). Table 3 shows the details of Models (eq 3).

These results indicate that for high canopy plants, pasture height may be more accurately estimated by VIs that control for variations in soil background effects as well as atmospheric induced variations, than the standard NDVI.

TABLE 4. ESTIMATES OF COEFFICIENTS AND MEASURES OF MODELS ADEQUACY TO VEGETATION HEIGHT AND VIs FROM DIFFERENT SENSORS.

Sensor/	Model parameters			Model fit	
VIs	c	a	b	R^2	p
MODIS_EVI	.414	1.398	-.072	.672	.003
FSp_EVI	.455	1.147	-.021	.604	.003
MODIS_NDVI	.636	.467	-.055	.546	.004
FSp_NDVI	.744	.403	-.049	.436	.006

Data from both test sites (n= 35). FSp: Field spectroradiometer sensor

5. CONCLUSIONS

In this study, VIs derived from MODIS-TERRA and field measurements were compared for their performances to estimate phenology and plant height of semi-natural meadows having a very high canopy cover.

The NDVI had great sensitivity to crop growth changes during greenup, whereas the EVI exhibited more sensitivity at the pick of the maximum green biomass.

The relationship between vegetation height and both VIs fit a logistic model. The EVI from MODIS explained 67% of the in-season plant height variability. While all the VIs were very sensitive to changes in plant height at the beginning of season, the NDVI became insensitive to additional plant growth when the pasture reached about height 40cm.

These results suggest a great sensitivity of EVI temporal profile from MODIS to detect the main phenological events and plant height of semi-natural meadows, even in situations of high plant height. Since the biomass and LAI are parameters highly related with vegetation height, the information derived from this study might help to understand the impact of management practices on vegetation dynamics and to compare the differences of vegetation dynamics between test sites and years in response to inter-annual climatic variations.

7. AGNOWLEDGMENTS

The authors wish to thank “Fundação para a Ciência e a Tecnologia” (FCT), LAMSAT_XXI project (PTDC/AGR-AAM/67182/2006) and A. Moura DRAPN for helping with field work.

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